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Water use in three rice flooding management systems under Mediterranean climatic conditions

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Abstract

Andalusia is the main rice producing region in Spain (40,000 ha). During the last decade it has suffered several years of water shortage leading to a decrease in crop area. In this work, studies have been performed to optimise water delivery and energy costs, comparing three flooding management systems: 1) irrigating seven days a week (control system: traditional continuous flooding system), 2) five days a week and 3) four days a week (maintaining the traditional irrigation management until 55 days after seeding in both tested systems). Total water used (water delivery) in 2000 corresponded to 44,917 m^3 ha^{-1} (traditional), 34,445 m^3 ha^{-1} (five days a week) and 29,209 m^3 ha^{-1} (four days a week). In 2001 these values were 45,607, 34,271 and 28,958 m^3 ha^{-1} respectively. No significant differences (LSD > 0.05) were found among the three flooding management systems in rice growth and yield. In 2000, irrigating five days a week, 23.31% of pumping energy was saved, and 34.97% when irrigating four days a week. In 2001 these values were 24.86% and 36.51%, respectively. These improvements, combined with the generalisation of integrated production procedures, will render Andalusian rice production more sustainable.

Additional key words: energy costs, flooding management, growth and yield, *Oryza sativa*, water deliveries, water use efficiency.

Resumen

Uso del agua en tres sistemas de riego para arroz bajo clima mediterráneo

Andalucía es la región productora de arroz más importante de España (40.000 ha). Durante la última década ha sufrido varios años de sequía en los que se ha dado un descenso de la superficie cultivada. En este trabajo, se han realizado estudios sobre la optimización del volumen de agua de riego y su coste energético mediante la comparación de tres sistemas: 1) sistema control, riego tradicional continuo (siete días por semana), 2) cinco días por semana, y 3) cuatro días por semana. En estos dos nuevos sistemas se mantuvo el riego tradicional durante los primeros 55 días tras la siembra. El volumen de agua de riego aplicada en 2000 fue de 44.917 m^3 ha^{-1} (sistema tradicional), 34.445 m^3 ha^{-1} (cinco días a la semana) y 29.209 m^3 ha^{-1} (4 días a la semana). En 2001 estos valores fueron de 45.607, 34.271 y 28.958 m^3 ha^{-1}, respectivamente. No se encontraron diferencias significativas (LSD > 0,05) en cuanto al desarrollo de la planta y a la producción entre los tres sistemas de riego ensayados. En el año 2000, regando cinco días, se ahorró el 23,31%, y regando cuatro días el 34,97% de la energía de bombeo consumida en el riego tradicional. En 2001, estos valores fueron 24,86% y 36,51%, respectivamente. Estas mejoras, junto a los ya generalizados procedimientos de producción integrada, harán la producción andaluza de arroz más sostenible.

Palabras clave adicionales: coste energético, crecimiento y rendimiento en grano, dosis de riego, eficiencia del riego, manejo del agua, *Oryza sativa*.

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Introduction

The Andalusian rice-growing region is located at the final stretch of the Guadalquivir river. Its climate is characterised by warm and dry summers, with clear and long days. The soil is of sedimentary origin, clayey, saline and poorly drained.

Bearing in mind that there are some differences in the types of soil and, more importantly, in the policies of the different irrigation districts, the seasonal water delivery for the Andalusian rice crop ranges from 20,000 to 45,000 m^3 ha^{-1}. Water losses due to runoff at the lower ends of rice fields are comparatively very high (between 11,000 and 31,000 m^3 ha^{-1}). However, water recycling is important in rice production areas (data supplied by the Guadalquivir basin authority, *Confederación Hidrográfica del Guadalquivir*, 2004).

Basins (rice paddies) are traditionally irrigated under a continuously flooded, flow-through system. Most of the irrigation water is pumped from the Guadalquivir river through the Irrigation Districts. Once the water is pumped up, it is conveyed through canals to the farms.

The entry of water into the uppermost basin is controlled by one or several inlet gates. In a rice basin (Fig. 1), the water flow is regulated by drop structures called «boxes», placed in the lower level of each basin. These allow the water to flow into lower basins. Flow depth can be adjusted by adding or removing flash boards from the grooves in the sides of the boxes in which they are set. At the end of the series of interconnected basins water falls into an open ditch through one or several outlet gates.

Although rice is flooded throughout most of the growing season, its evapotranspiration (ET) is similar to that of pasture, alfalfa or cotton (Grigarick *et al*., 1992). Continuous flooding is not indispensable to obtain high yields. De Datta (1975) indicated that more than 7 Mg ha^{-1} can be harvested under upland conditions.

Bouman (2001) reported several studies on nonflooded irrigated rice using sprinkler irrigation conducted in Texas and Louisiana (Westcott and Vines, 1986; McCauley, 1990). As a result of these studies, there was an irrigation water conservation of 20-50% compared with flooded rice requirements, depending on soil type, rainfall and water management. Nevertheless, there were yield losses of 20-30% among the highest yielding cultivars (producing 7-8 Mg ha^{-1} under flooded conditions) while the most drought-resistant cultivars yielded the same under both conditions (5-6 Mg ha^{-1}).

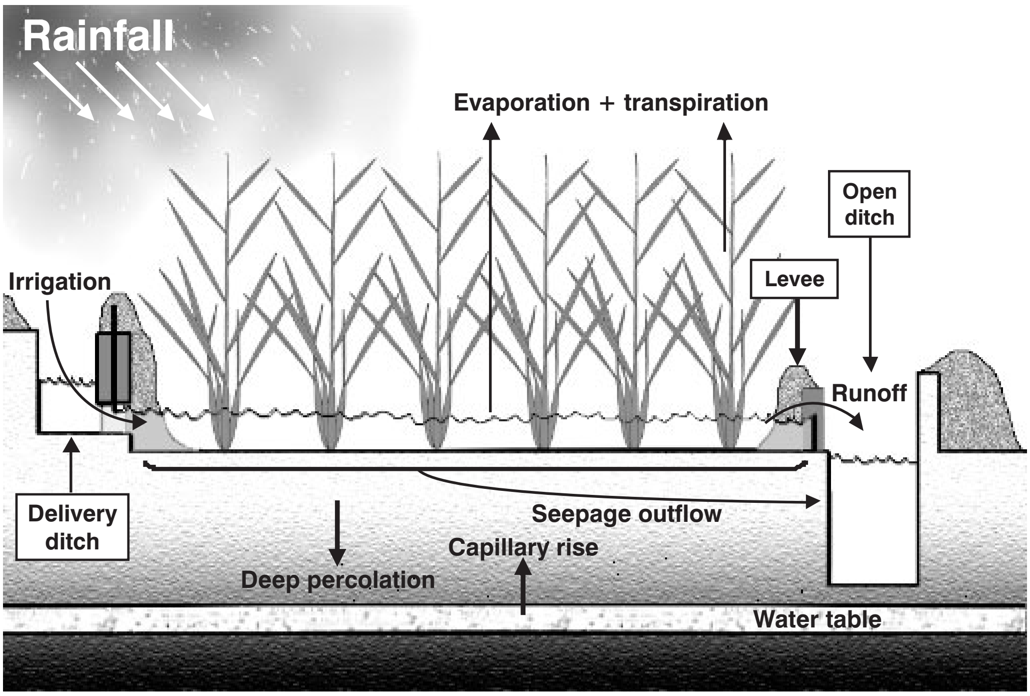

Figure 1. Water balance of a rice field (schematic). The water balance can be established as: Irrigation (deliveries) + Rainfall = ET + Percolation + seepage outflow + runoff.

In an enclave with sandy and non saline soil in Extremadura (Southern Spain) pivot irrigation has been introduced. Rice seeding is performed directly over the stubble of crops such as corn, obtaining yields very close to those of flooded rice. In Andalusian saline conditions, flooding is essential for soil leaching (controlling salinity levels), as well as to perform an effective weed control.

The term «efficiency» has a wide use depending on the purpose and the domain of interest on which we are focused: water-use efficiency, water application efficiency, and others (Israelsen, 1950; Jensen, 1980). Irrigation efficiency is defined as the ratio of the water required for an intended purpose divided by the total amount of water diverted to a spatial domain (Jensen, 1980; Wolters and Bos, 1989). From the perspective of irrigation, efficiency can be defined as the ratio between the total amount of water consumed in evapotranspiration, and the total input of water, be it rainfall or irrigation. From a physiological point of view, water use efficiency can be defined as the yield obtained per volume of water consumed by evapotranspiration or used for irrigation.

When discussing irrigation efficiency, particular attention must be paid to the recycling of water for other agricultural or non-agricultural uses in the river basin (Seckler *et al*., 1998).

In Andalusia runoff water is recycled by pumping it from the open ditches. This process can be repeated one or two times, creating an almost closed circuit. Water can be recycled by pumping it from the river downstream, too.

In this work, traditional continuous irrigation is compared to two discontinuous irrigation schemes, with the objectives of: 1) determining the volume of used water (deliveries) in each of the three irrigation systems; 2) assessing the agronomic response of the crop; and 3) determining the pumping energy saving associated with the two proposed systems.

Material and Methods

In the lower Guadalquivir area irrigation water (water deliveries) constitutes the main source of water used by rice (Fig. 1), since rainfall is only about 90 mm during the crop season and the capillary rise of water is not significant.

In order to determine ET and ET_0, climatic data from the Isla Mayor Meteorological Station were used. The Penman-Monteith method was used for this purpose. According to the Rice Integrated Production Specific Regulations (BOJA, 2000) the crop coefficient was considered to be 1.10 during the whole crop cycle.

Since the soil is clayey (68% clay), deep percolation is often low. Moreno *et al.* (1981) reported values of saturated hydraulic conductivity < 1 mm h^{-1} for the heavy clay soils of the marshes of the Guadalquivir river under rice cultivation. For the reclaimed and irrigated soils of this area Moreno *et al.* (1995) also found values of saturated hydraulic conductivity < 1 mm h^{-1} at a depth below 0.5 m in the soil profile.

ET and runoff are very relevant water outputs. Runoff and most of the seepage outflow that end in the open ditch are available for recycling. Since water recycling is widespread in the Andalusian rice area, the actual water consumed can be considered as the sum of ET, deep percolation (if it can not be recycled) and the percentage of runoff that can not be recycled.

The trial was conducted in 2000 and 2001 on a typical clayey soil in Puebla del Río (Seville), in the heart of the Andalusian rice production area. The chosen variety was Thaibonnet (L-202), which is widespread in the area.

The experiment was based on a complete randomised block design with three replications (Fig. 2). Elemental plots were 6.25 ha in size. In 2000 the seeding was performed by plane on April 21st and the harvest on October 7th by combine. In 2001 the seeding was performed on April 25th and the harvest on October 11th. Standard cultural practices were adopted in both years. Phosphorus (50 kg ha^{-1} P_2O_5) and nitrogen (150 kg ha^{-1}), in the form of urea 46%, were applied before seeding as usually recommended in the area.

The traditional plus the two discontinuous flooding systems maintained the traditional irrigation practices until the herbicide for sedges and broadleaves was applied (55 days after seeding). During these first 55 days (Fig. 3) the initial flooding was performed and the water level was lowered on two occasions, following standard local practices: the former to help the plantlets to take root and the second one to apply contact herbicides. Nevertheless, the soil was never completely dry. From then on, the continuous and the two discontinuous (with irrigation 5 and 4 days a week) irrigation treatments were started. The flow rate in the

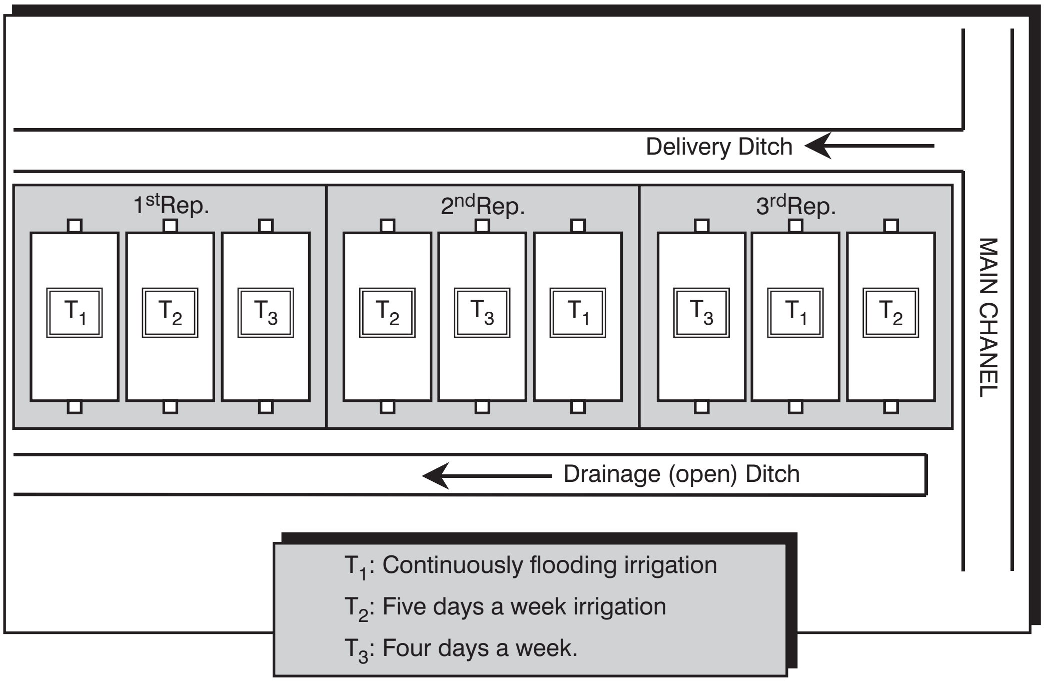

Figure 2. Experimental layout. The area of the elemental plot is 6.25 ha.

nine elemental plots was adjusted to 3 L s^{-1} ha^{-1} during the irrigation season, maintaining this flow until two weeks before harvest. At the end of the crop cycle the water level was lowered to 5 cm in order to ease the work of the combines. The irrigation volume was recorded by a propeller flow meter (mod. *Tecnidro SVL Genoa*) located at the inlet of each rice basin.

The inlet gates were closed for two days a week (for the *five days a week* irrigation plots) and for three days a week (for the *four days a week* irrigation plots).

The observations recorded in every elemental plot included:

— Heading (days from sowing to 50% heading): de *visu.*

— Ripening (days from sowing to 20% humidity grain): four samples of 100 grains were taken.

— Plant height (length between the ground and the tip of the panicle at flowering): 40 plants were sampled.

— Lodging (%) (at harvest time): de *visu.*

— Panicles m^{-2}: four samples were taken (0.25 m^2 per sample).

— Grains / panicle: the sum of empty (blank) and filled grains was calculated among 40 panicles.

— Blank grains (%): the number of blank grains was calculated among 40 panicles.

— Weight of 1,000 grains (filled and blank).

— Grain yield: the whole plot was harvested (14% moisture).

—Flow depth: recorded daily at 12:00 h, using millimetric stick meters located in each elemental plot.

The following water use efficiencies were calculated:

E_1 = Evapotranspiration / (Water deliveries + Rainfall)
E_2 = Grain Yield / Water deliveries

Regarding the pumping energy, the electric consumption data were provided by the Cantarita Irrigation District.

ANOVA analysis was performed, according to Snedecor and Cochran (1970), and Steel *et al.* (1997).

Results and Discussion

The estimated water deliveries and flow depth evolution in the three flood management systems during the two years of study are shown in Fig. 3.

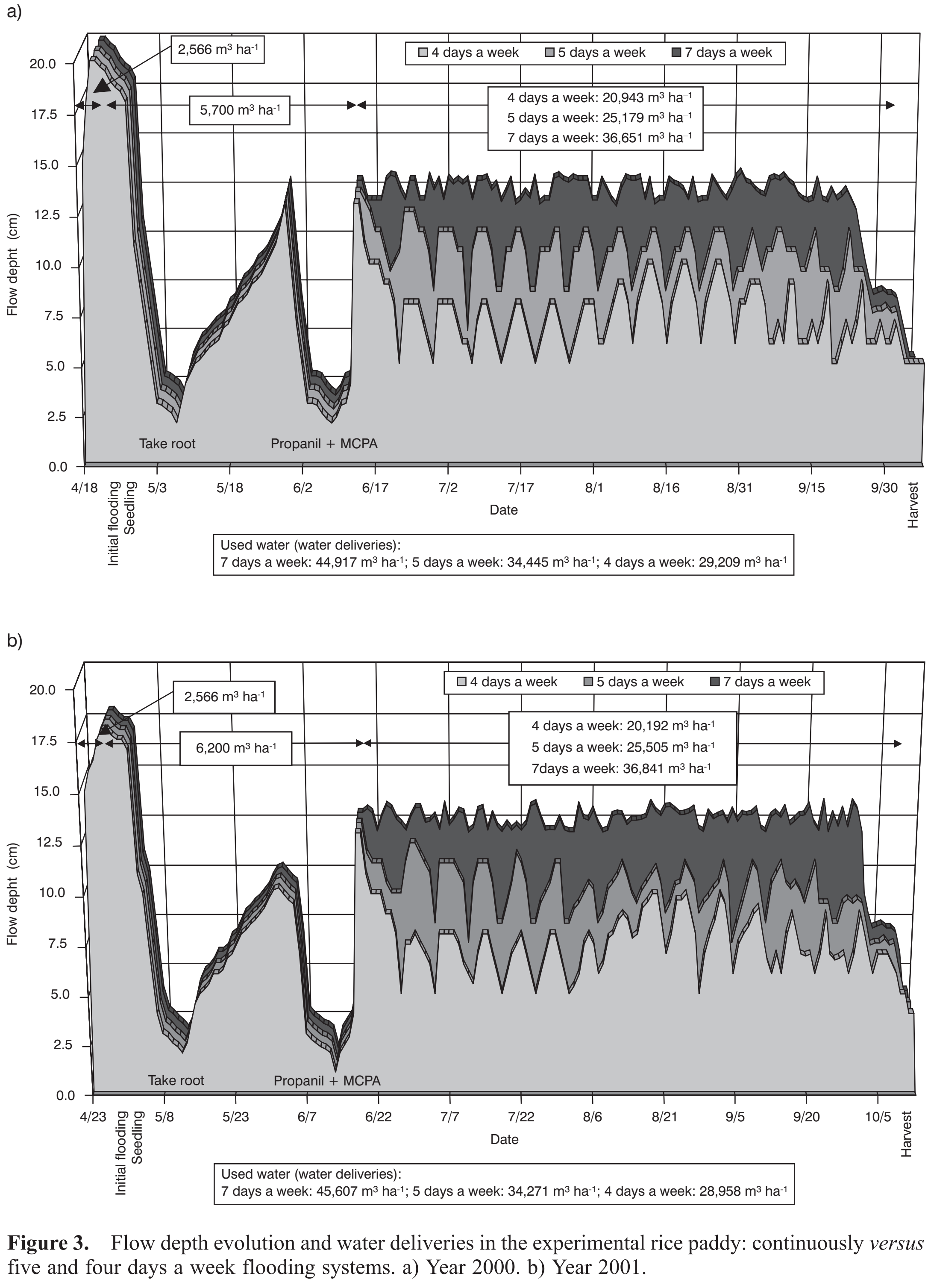

Figure 3. Flow depth evolution and water deliveries in the experimental rice paddy: continuously *versus* five and four days a week flooding systems. a) Year 2000. b) Year 2001.

In 2000, 2,566 m^3 ha^{-1} of irrigation water were applied for the initial flooding, and an additional irrigation volume of 5,700 m^3 ha^{-1} was delivered before the irrigation treatments began (2,566 m^3 ha^{-1} and 6,200 m^3 ha^{-1} in 2001, respectively). Most of the irrigation water was applied after the application of contact herbicides (55 days after seeding).

Total water deliveries (average of the tree replicates) in 2000 were 44,917 m^3 ha^{-1} (traditional), 34,445 m^3 ha^{-1} (five days a week) and 29,209 m^3 ha^{-1} (four days a week). In 2001 these values were 45,607, 34,271 and 28,958 m^3 ha^{-1} respectively. A similar volume of water was applied in each of the three elemental plots of all treatments, so that the differences among them were not significant. Relevant water conservation was obtained with the two proposed systems: 10,472 m^3 ha^{-1} for five days a week and 15,708 m^3 ha^{-1} for four days a week flooding systems, in 2000; 11,336 m^3 ha^{-1} for five days a week and 16,649 m^3 ha^{-1} for four days a week flooding systems, in 2001.

Table 1 lists the results for growth parameters (days to heading, days to maturity, plant height, lodging) and yield components (panicles m^{-2}, grains per panicle, blanks (%), grain weight, grain yield). Similar responses were obtained in the three irrigation systems, in both campaigns. The two proposed systems reached the same grain yield as the traditional one, with relevant water conservation.

Some water conserving rice irrigation techniques used around the world include maintaining a low water level, growing in saturated soil conditions and alternating wetting and drying cycles. These techniques have been reported to reduce water input by 40-70%. Such management schemes can be introduced without changes in grain yield (Hatta, 1967; Tabbal *et al*., 1992; Singh *et al*., 1996). In the last fifteen years these techniques have allowed the cultivated area to be increased to one million hectares in the Guangxi Autonomous Region and Hunan Province in Southern China (Guangxi Water and Power Department, 1996). Although the proposed irrigation techniques differ from those reported in the above references, and therefore the paddy flow depth evolution can not be compared, similar results were obtained in our experiments regarding the reduction of water input without affecting crop yield.

Table 2 lists the results on efficiency (E_1 and E_2) obtained with the three techniques. Relevant differences were found in all cases. E_1 increased as the irrigation frequency decreased from seven to five and four days a week, in both seasons. Similar results were obtained for E_2.

Discontinuous flooding brought about a reduction in pumping time, resulting in a relevant energy saving, and an important reduction in the overall costs

Table 1. Effect of three water managements on rice growth and yield. Seville (Spain). Results are presented for 2000 and 2001

	Days to heading	Days to grain maturity (20% moisture)	Plant height (cm)	Lodging (%)	Panicles per m^2	Grains per panicle	Blanks (%)	1000 grain weight (g)	Grain yield (14% moisture) kg ha^{-1}
2000									
Continously flooding	90	135	72.7	0	791	53	10.3	28.9	8,267
Five days a week	90	136	72.8	0	786	54	9.4	29.1	8,319
Four days a week	89	134	72.2	0	780	52	10.4	28.7	8,114
Average	90	135	72.57	0	786	53	10.03	28.9	8,233
LSD (95%)	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	—	—	5.8	—	13.9	14.2	15.1	3.9	7.2
2001									
Continously flooding	91	137	72.2	0	782	54	9.5	28.2	8,396
Five days a week	92	137	73.1	0	786	56	8.8	28.8	8,246
Four days a week	88	133	71.9	0	769	53	10.3	28.5	8,003
Average	90	136	72.4	0	779	54	9.53	28.5	8,215
LSD (95%)	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	—	—	4.46	—	12.3	15.1	15.7	4.2	6.9

NS: non significative. LSD: least significance difference. CV: coefficient of variance.

Table 2. Hydrological parameters, grain yield and efficiency for the three irrigation management practices and the two irrigation seasons (2000 and 2001)

	Water (mm)		
	Continuously flooding	**Five days a week**	**Four days a week**
2000			
Water deliveries (I, mm)	4,492	3,444	2,921
Rainfall (R, mm)	90	90	90
Total (T, mm)	4,582	3,534	3,011
Evapotranspiration (ET, mm)	820	820	820
Grain yield (Y, kg ha^{-1})	8,267	8,319	8,114
Efficiency$_1$ (E_1, kg mm^{-1}) = ET/T	0.18	0.23	0.27
Efficiency$_2$ (E_2, kg mm^{-1}) = Y/I	1.84	2.42	2.78
2001			
Water deliveries (I, mm)	4,560	3,427	2,896
Rainfall (R, mm)	88	88	88
Total (T, mm)	4,648	3,515	2,984
Evapotranspiration (ET, mm)	890	890	890
Grain yield (Y, kg ha^{-1})	8,396	8,246	8,003
Efficiency$_1$ (E_1, kg mm^{-1}) = ET/T	0.19	0.25	0.30
Efficiency$_2$ (E_2, kg mm^{-1}) = Y/I	1.84	2.41	2.76

Table 3. Energy consumption and savings between conventional rice irrigation management and the two proposed irrigation treatments based on discontinuous irrigation

	Pumped water (m^3)	**Applied energy (kw h^{-1})**	**Cost (€)**	**Energy saving (kw h^{-1})**	**Economic saving (€)**	**Energy saving (%)**	**Economic saving (%)**
2000							
7 days	44,917.00	786.05	55.70	—	—	—	—
5 days	34,445.00	602.79	42.71	183	12.99	23.31	23.3
4 days	29,209.00	511.16	36.22	274	19.48	34.97	35.0
2001							
7 days	45,607.00	798.12	56.55	—	—	—	—
5 days	34,271.00	599.74	42.50	198	14.06	24.86	24.9
4 days	28,958.00	506.77	35.91	291	20.64	36.51	36.5

—: no savings were registered (control water treatment).

(Table 3). These findings have relevant economic and environmental consequences.

The results of this research suggest that there are grounds for obtaining relevant water conservation in traditionally irrigated rice systems by using intermittent irrigation. In fact, simple changes in the irrigation schedule can lead to an increase in irrigation efficiency from 0.18 to 0.27, with water and energy conservation exceeding 35% of the water used in traditional irrigation.

The combination of the reported improvements in water and energy management, together with the generalised integrated rice cultivation procedures will render Andalusian rice production more sustainable. While 5 or 4 days of weekly irrigation seems to constitute a technically feasible alternative, a further reduction in the irrigation period could result in a salinity build up which could affect crop yield and a number of soil physical and chemical parameters.

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